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Effect of de-icing salt as winter maintenance for corrosion of steel piles on bridges

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Abstract. Corrosion can have significant long-term effects on the structural resistance of steel piles in ground. There is a possibility that this effect can be intense if ground contains chlorides, sulphites or other aggressive chemicals. Also de-icing salt (NaCl) used on roads during winter maintenance may have effect on the corrosion of steel piles. In this research project a series of site investigations and laboratory tests have been conducted to investigate the effect of de-icing salt for corrosion on steel piles. Totally 12 sites were investigated, partly from locations where de-icing salt has been used and partly where de-icing salt has not been used. Most of the piles were part of bridge structures, but the study includes also data from a few special test piles. Investigated steel piles have been in ground for five to 24 years. The results show that the corrosion and its rate are low. The detrimental effect of de-icing salt on corrosion is negligible.

1. Introduction

Design standards and manuals give guidelines for determining the corrosion of steel piles. Most often these guidelines consider the effect of different types of soil and/or water where the piles are installed. However, the effect of de-icing salt on corrosion is not well known and usually its influence is not included in these guidelines.

This study was made to examine the amount of corrosion in steel piles located on areas where de-icing salt is used and where de-icing salt is not used.

2. Background for research

2.1. De-icing salt as winter maintenance for roads

De-icing salt together with snow ploughing and other maintenance operations is used to provide road conditions for traffic which ensure that movement and transports can be handled effectively and safely during winter [1]. De-icing salt can be used as a preventing measure in advance to avoid freezing conditions and for melting the ice, slush and snow. Sodium chloride (NaCl) is the most common de-icing salt in winter maintenance in Finland and globally. In Finland there are six winter maintenance classes depending on the significance of the road section.

De-icing salt is used regularly for antiskid treatment in the three highest winter maintenance classes Ise, Is and I and additionally in class Ib in exceptional weather conditions. Finnish Transport Infrastructure Agency (FTIA) has a road network altogether roughly 78 000 km and from which round 9 500 km belongs to above mentioned three highest classes, and where 69% of the total traffic and 72%



from heavy vehicle traffic occurs. Yearly altogether FTIA uses 80 000 - 100 000 tons of NaCl and typically the amounts per road kilometers varies from 2 tons/km up to 20 tons/km per year. Climate change is increasing extreme variations in weather and brings up new challenges resulting increase of actions to maintain roads in satisfactory condition and puts pressure to increase the use of de-icing salt [1].

Use of de-icing salt increases the chloride content of soil and groundwater. FTIA is monitoring the chloride content of groundwater nationwide in cooperation with the Finnish environmental administration. There are about 230 monitoring points in Finland and samples are taken 2-4 times a year. According to one long-term study [2], between years 1955 - 2014, monitoring of groundwater in the aquifers along the first Salpausselkä ice-marginal formation, the chloride content trend was rising or strongly arising in 49% of the observation points. In the individual groundwater samples, the chloride concentrations varied from 0.4 to 700 mg/l. As for reference, chloride concentration of typical Finnish groundwater is below 25 mg/l.

2.2. Previous literature studies of effects of chlorides to corrosion

According to VTT [3], no studies where de-icing salt or NaCl as a major input to corrosion, was found. VTT found many studies where chloride content of soil or groundwater was analyzed and in general it's recognized that soluble salts (chloride, sulphite) have adverse effects. These decrease the resistivity of soil, have an influence on electrochemical reactions on the surface of steel and chlorides contribute on decomposition of protective corrosion product layer. Clear correlation between chloride content of soil or groundwater and corrosion rate was not found.

2.3. Current Finnish guidelines and recommendations concerning sacrificial corrosion values

The design of structures in Finland is done according to the Eurocode design standards. Design of steel piles is covered by Eurocode 3 Part 5 [4] and it also gives a table of recommended values for the loss of thickness due to corrosion for piles in soils, with or without groundwater, shown in Table 1. In Finland these recommendations are used without any Nationally Determined Parameters in National Annex.

Table 1. Recommended value for the loss of thickness [mm] due to corrosion for piles and sheet piles in soils, with or without groundwater [4]

Required design working life	5 years	25 years	50 years	75 years	100 years
Undisturbed natural soils (sand, silt, clay, schist,)	0,00	0,30	0,60	0,90	1,20
Polluted natural soils and industrial sites	0,15	0,75	1,50	2,25	3,00
Aggressive natural soils (swamp, marsh, peat,)	0,20	1,00	1,75	2,50	3,25
Non-compacted and non-aggressive fills (clay, schist, sand, silt,)	0,18	0,70	1,20	1,70	2,20
Non-compacted and aggressive fills (ashes, slag,)	0,50	2,00	3,25	4,50	5,75

Notes:

- 1) Corrosion rates in compacted fills are lower than those in non-compacted ones. In compacted fills the figures in the table should be divided by two.
- 2) The values given for 5 and 25 years are based on measurements, whereas the other values are extrapolated.

In addition to Eurocodes FTIA has published also series of Non-Contradictory Complementary Information (NCCI) to define how Eurocodes and National Annexes are to be applied in FTIA projects

in Finland. NCCI 7 [5] considers the applying of Eurocode 7, Geotechnical design. Since steel piles are used in foundations they are considered as part of geotechnical structures.

According to [5] the steel piles on roads belonging to winter maintenance classes Ise, Is and 1, and on bridges crossing these roads, are expected to be corroded totally away in the effective area of de-icing salt. The effective area is defined to extend horizontally 12 m from the edge of the road and vertically 2 m below the lowest permanent groundwater table. Large diameter steel piles are very often used in bridge foundations in Finland. Due to this regulation the steel casing of the piles cannot be fully utilized in design and the top part of the piles is therefore designed as reinforced concrete structure.

Soil corrosion on steel structures has been widely studied in references [3, 6-18].

3. Execution of the research

3.1. Selection of the investigated piles

Potential bridges were selected from FTIA's digital register of bridges and other civil engineering structures ("Taitorakenrekisteri") with the help of suitable search filters. Due practical reasons to avoid challenging excavations with sheet pile walls, selected bridges were cases where tubular steel pile extends straight as a column to the upper structure of the bridge. Eight different bridges and one noise barrier were selected. Two of the bridges were railway bridges where no de-icing salt was used, rest of the bridges and the noise barrier were chosen from road sections where winter maintenance class is Ise, Is or I i.e. where de-icing salt was regularly used.

In addition to investigated bridge and noise barrier piles, three test piles were installed for future corrosion investigations in 2014 close to railway line Ruha - Lapua. As a part of the current study, they were decided to be lifted up and investigated and to represent situations where there is no de-icing affecting. After investigations, the piles were installed back into the ground to enable investigation of corrosion values again after longer period of time.

3.2. Excavation pits and test piles

Bridge piles were exposed by making a sloped excavation around the pile, Figure 1. Typically head of the pile was in depth of 0.5 - 1.0 m. Groundwater flow into pit and stability of sloped excavation limited the excavation depths and piles could be exposed so that 0.5 - 1.5 m of the steel pile was visible. Special test piles were lifted up with vibrator.

After a pile was exposed, a visual inspection and photographing of the surface of the pile was done before and after cleaning with pressure washer.

In Figure 1, it can be seen the points marked on the exposed pile surface. The thickness of the pile wall was measured from these points by using ultrasonic method. In this particular case on site O-1648 the distance between the measured rows was 90 mm and between the columns 150 mm.

3.3. Material thickness measurements

As it was mentioned earlier, the steel piles, which were part of construction structure, were exposed by making an excavation. The special test piles were lifted up from the ground for the measurements. The test methods to characterize the state of corrosion were visual inspection and photographing of pile surfaces on site, soil condition characterization and groundwater table. Ultrasonic testing of the wall thickness-were also carried out on site, and to confirm the reliability of the ultrasonic measurements, in three first cases wall thickness-were measured in laboratory using calibrated micrometer and the surfaces of the specimens were characterized by optical profilometer to see the actual depth of the corrosion pits on the pile surface.



Figure 1. Bridge O-1684. Pile is cleaned and measurement points are marked.
Steel pile is visible for 1.2 m below concrete column.

The wall thickness was measured on site using GE Phasor XS ultrasonic tester. During the test, the highest pulse reflected from the inner side of the tube wall was measured. The equipment was calibrated with 7.98 mm, 13.67 mm and 15.12 mm thick, polished calibration samples made of structural steel. The measuring range used was calibrated using two or three of these samples, and in control calibration between the measurements, one calibration specimen nearest to the measured wall thickness value was used to confirm the calibration of the measurement. The calibration of the measurement was always checked also after the measurement and during the measurement if the total measuring time exceeded 30 minutes.

After photographing the original state of the pile surface a pressure washer was used to clean the pile surface to be measured. To remove the rust layer about 20 mm in diameter, the surface was ground with sandpaper from each measuring point so that clear and clean steel surface became visible. Signal conducting gel was used between the ultrasonic probe and the steel surface.

Accuracy of ultrasonic measurement was found to be satisfactory on general corrosion keeping in mind, that the piles studied were in rolling condition and the wall thickness of these kinds of piles can vary 0.1 - 0.2 mm after they are manufactured. The method was not able to detect small dimensional corrosion pitting. Exact original wall thickness of steel piles was known in one site and in three test piles based on quality documents and records of steel pile manufacturer. In other sites the nominal thickness was known from design drawings and real original thickness had to be evaluated based on measurements carried out from such pile wall areas where the corrosion was not present, i.e. from locations where the rolling scale could still be found from the steel surface.

For analyzing the chlorine concentrated on the corrosion layers, samples were scratched off from the pile surfaces. In laboratory the samples were glued on the sample holders and analyzed with Jeol IT 500 electron microscope equipped with EDX analyzer. When analyzing the results presented in 6 chlorine content above 0.1 % can be reliably measured.

3.4. Soil and groundwater sampling

Where excavation level reached the level of groundwater (aquifer of perched groundwater), a water sample was taken and analyzed in laboratory. Acidity, chloride and sulphate concentrations and also electrical conductivity of water were analyzed. Two soil samples were taken per bridge, first one from man-made fill layer and second one from subsoil. Soil type and grain distribution were visually determined, and water content measured.

At Ruha-Lapua test pile sites, ground investigations and laboratory analyses of chemical properties were done during years 2013 - 2014 and were available for this research. No new analyses were done during this study.

4. Characteristics of investigated piles and test sites

Locations of test piles are shown in Figure 2. Investigated piles have been in ground from five to 24 years. Bridges were constructed from nine to 24 years ago. In six bridge sites, groundwater table was reached, so investigated piles were located in the zone of fluctuating water table where it's assumed that conditions for corrosion are the severest. In three sites, one was the noise barrier pile, investigated piles were located above groundwater and exact depth of groundwater table was not known. Groundwater table and conditions on three test pile sites could be determined from previous ground investigations.

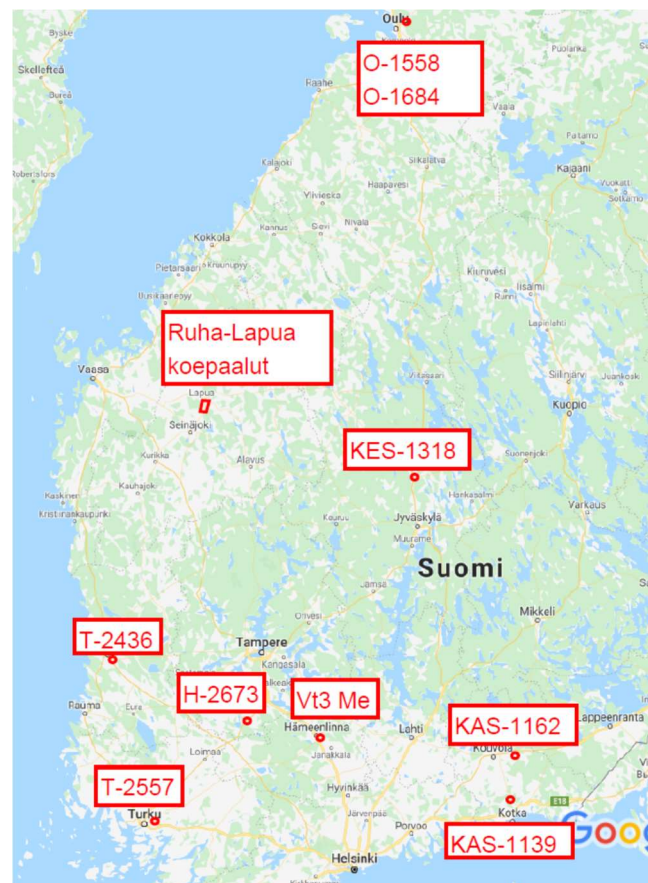


Figure 2. Locations of investigated piles. Letters and numbers are the identification numbers of the bridges. Vt3 Me is the investigated noise barrier piles.

The main characteristics of the bridge and noise barrier piles are presented in Table 2.

Table 2. Characteristics of investigated bridge and noise barrier piles and test sites

Identification	T-2436	H-2673	T-2557	Kes-1318	Kas-1139	Kas-1162	O-1558	O-1684	Vt3 Me noise barrier
Age [years]	18	13	12	9	22	16	24	11	24
Fill layer ^{a,c} , thickness [m]	grSa 0-0,45	grSa 0-0,45	crRo 0-0,15	mix of clSi, crRo, Sa 0-0,45	Gr 0-0,2	crRo 0-0,65	Sa 0-0,5	Sa 0-0,6	Sa and Sa containing organic matter ^b
Subsoil below fill layer ^c	clSi	Clean clay	Fat clay	Fine Sand	Sa	Fine Sand	siSa	siSa	^b
Groundwater ^a depth [m]	0,9	1,2	1,0	Below excavation	0,2	Below excavation	0,5	0,5	Below excavation
De-icing: average amount/year [t/km], winter maintenance class	6,8 Is	7 Is	6 Is	5,5 Is	No	No	20 Ise	20 Ise	12,8 Ise
Nominal pile size (D/t) [mm]	762/11,1	813/12,2	813/12,5	914/14,2	610/12,5	914/12,5	762/16	711/12,5	193/6,3
Exact original wall thickness t [mm]	Not known	Not known	Not known	Not known	Not known	Not known	Not known	11,95-11,96	Not known
Chloride concentration in water sample [mg/l]	330	110	220	-	7,5	-	720	450	-

^a Measured from the head of the steel pile.

^b Exposed pile(s) were totally on man-made fill layer

^c Gr=gravel, Sa=sand, Si=silt, Cl=clay, crRo=crushed rock

5. Results

Altogether piles from eleven sites in different parts of Finland were characterized during the studies. Most of the piles were measured using ultrasonic equipment and to confirm the reliability of the measurement procedure, three first studied pile specimens were cut off and measured in laboratory with optical profilometer and the thickness of the pile walls was measured with micrometer.

As a general result of the studies it can be concluded that the corrosion found from the piles is negligible. Highest corrosion levels were found from site Highway 3 noise barrier and from site T-2436. In Figure 3 is presented the pile surface exposed below ground in site T-2436. It can be seen that there is corrosion and corrosion pitting on the pile surface in the man-made fill layer. The surface inside the subsoil seen in the lower part of the Figure 3 has remained in uncorroded state and the original wall thickness of the pile can be measured from that area.



Figure 3. Excavation T-2436 and pile surface: on the upper part of the image can be seen corrosion on the pile surface in the man-made soil region, the surface inside the subsoil is remained in uncorroded state.

The results of the measurements on the site T-2436 are presented in the Figure 4 and 5. The wall thickness measured with micrometer from the pile inside subsoil was 10.95 mm and 10.99 mm measured with ultrasonic equipment respectively. The thickness measured from man-made fill layer area was with micrometer 10.87 mm and with ultrasonic equipment 11.00 mm. So, it can be seen that the measurements performed using a micrometer are more sensitive to pitting corrosion so that the measured average pile wall thickness is lower than when measured using ultrasonic equipment. The same phenomena can be seen also in the results of all pile wall thickness measurements, where the deviation between the measuring points measured using micrometer is much higher at the man-made fill layer area.

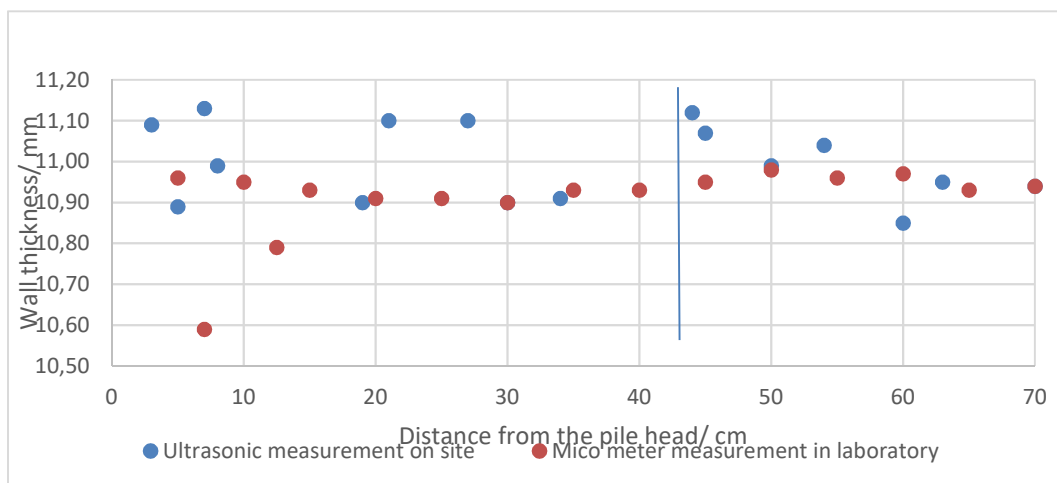


Figure 4. Example of the pile surface measurement T-2436 where the corrosion was found to be highest: Measurements with ultrasonic and with micrometer presented in same image. The original wall thickness is according to these measurements 10.90 - 10.95 mm measured from the subsoil region. The boundary between the man-made fill and subsoil is marked with blue vertical line.

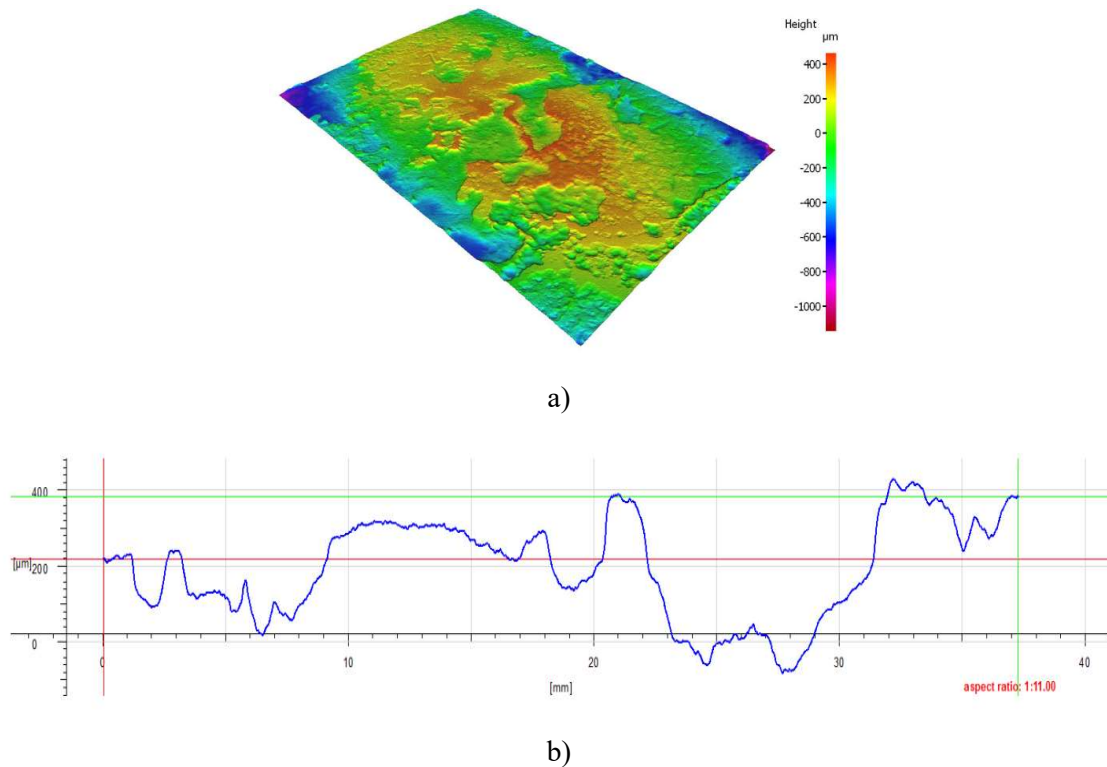


Figure 5. Deoxidized Specimen surface cut from the site T-2436 measured with optical profilometer. The deepest local corrosion pits were measured to be 500 µm. The pits presented seem to be rather widening than growing towards the pile inner surface (a).

Samples were scratched off from the pile surface to analyse of the salt contents of the pile surface layers. The samples were glued on the sample holders and analyzed with Jeol IT 500 electron microscope equipped with EDX analyzer. When analyzing the results presented in Figure 6 it has to be seen that chlorine content above 0.1 % can be reliably measured.

According to the results presented in Figure 6, the chlorine content is relatively low on the pile surface layers. Nevertheless, chlorine is present in most of the cases and in Kes-1318, O-1558, O-1684, H-2673 and T-2557 the chlorine content is clearly elevated. Since chlorine is evidently present it must be taken into account when considering the corrosion rate of the bridge piles.

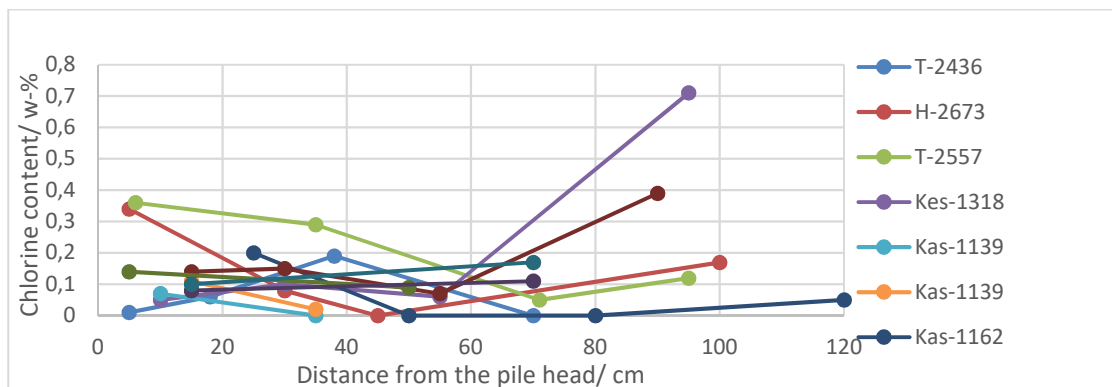


Figure 6. EDX-analyses of chlorine content measured from the samples scratched off from the pile surfaces.

Ruha-Lapua railway line test piles, altogether six 139,7/10 mm (D/t, lengths 6 and 12 meters) steel piles, were installed in 2014. Piles are longitudinally welded pipes and due to manufacturing process (cold forming and longitudinal weld), real wall thickness along perimeter of the pipe may vary $\pm 0.1-0.15$ mm according to measurement of one uplifted pile. All three test sites have variable ground conditions even though they are situated quite close to each other. One of the test piles, Alanurmo, is located in sand, Ulvila pile is located in muddy silt and clay layers, and Ravirata has peat as the uppermost soil layer and silt and clay layers deeper. Ulvila site has according to laboratory analyses quite aggressive soil conditions; in muddy silt layer just above and below groundwater table the sulphate content in soil is 3300 mg/kg and the acidity is pH 3.5. Despite that, according to the ultrasonic measurements, average loss of steel due corrosion was estimated to be only 0.04 mm in 5 year which correspond approximately 1 mm/100 years if corrosion rate is assumed to be constant.

6. Conclusions

Corrosion rate was found to be highest in fill layer at the zone where groundwater table varies. Based on results, amount of corrosion and corrosion rate was found to be low and no clear detrimental effect of de-icing salt to corrosion was found. In general, loss of thickness due corrosion was found to be well in line with the results found from literature for disturbed and undisturbed unaggressive soils. According to the measurements the loss of thickness is less than 0.3 mm after 25 years in use for undisturbed soils and under 0.7 mm for 25 years in use for disturbed soils. Uncertainties of the study were related to relatively small amount of investigated piles and uncertainties in input factors. There was no real comparison where other factors than de-icing could be eliminated when evaluating the results. Due to allowable tolerances in steel pipe manufacturing, and lack of manufacturing records of majority of the tested piles, the real exact wall thickness was not precisely known which may cause some error in findings. De-icing, according to water sample analyses, clearly has increased the chloride concentration of ground and groundwater but it's not known did these test sites represent the worst corrosion conditions related to de-icing salt.

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